VARIABLE CABLE LENGTH COMPENSATOR FOR VIDEO IMAGING SYSTEMS

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Field of the Invention

This disclosure concerns an invention relating generally to adjustment of signals in electronic imaging systems for better image quality, and more specifically to compensation of video signals in radiographic and fluoroscopic imaging systems to account for cables present in their video imaging chains.

Background of the Invention

Image quality in radiographic and fluoroscopic (X-ray) imaging systems is determined by a set of physical parameters such as noise, contrast, spatial resolution, etc., and it is affected by the signal transfer functions of individual system components such as the X-ray tube, image detector, video processor, digital processor, etc. Moreover, the imaging performance of the system is not only affected by the performances of the individual components, but also by their interaction. The variability of the interaction can be greatly affected by calibration of these systems during manufacturing and at their installation sites. It was previously often found that radiographic/fluoroscopic systems (and more specifically their video imaging systems) suffered from degraded image quality once they were assembled at their installation sites, even though the components of these systems had undergone extensive factory calibration. This occurred even where components were calibrated both individually (to account for their individual transfer functions) and taken together (to account for their collective transfer functions). This image degradation at the installation site led to greatly increased costs because the systems would then need to undergo extensive field recalibration and/or replacement of system components that were suspected of being defective. There was therefore a substantial need for apparata and methods for allowing rapid recalibration so that image quality could be optimized.

Summary of the Invention

It has been found that the video imaging subsystems of radiographic and fluoroscopic imaging systems are highly susceptible to the effects of the cables used to interconnect their various components. These cables vary in length depending on the particular installation site, and therefore the final installed cable length is not known at the time the video image chain is factory calibrated. If the cable length imparts conditions on the video chain which are different from those that were used to factory-calibrate the video subsystem, image quality at the installation site can be substantially degraded. As a result, the video imaging subsystem requires additional field calibration and/or replacement of components until image quality is raised to an acceptable level, and this greatly increases the time and cost burden of installation.

The cable compensator, which is defined by the claims set out at the end of this disclosure, is intended to be situated in a signal path of a video imaging system (such as the one in a radiographic/fluoroscopic imaging system) so that signal integrity is not degraded by the different cable lengths that might be present in the signal path at the installation site. The cable compensator may be situated in the signal path and set to an appropriate setting corresponding to the installed cable length, and will thereby equalize the video subsystem's frequency response with high precision from DC to a maximum frequency so that gain is unaffected across the range of video subsystem operating frequencies. An exemplary cable compensator in accordance with the invention includes a first path wherein a means for adjusting low frequency gain is situated between an input end and an output end, and a second path which includes an input end and an output end with several components situated therebetween: a means for adjusting high frequency gain, a variable resistance, and a parallel array of at least two capacitances. An output amplifier is also provided into which the output ends of the first and second paths are summed. The parallel array of capacitances, when taken in conjunction with the output amplifier and with one or more resistances provided in series with the capacitances, effectively allows the second path to act as an array of high-pass filters. As will be described at greater length later in this disclosure, when

capacitance and resistance values are appropriately chosen and the low and high frequency gain adjustment means are properly tuned, the compensator can be situated in a signal path, the variable resistance of the second path can be set to a resistance value proportional to the length of the variable-length cable in the signal path, and the compensator will then provide a compensator output signal which is substantially similar to the cable input signal across the range of target signal frequencies. Most preferably, the variable resistance in the second path is provided in the form of a discretely variable resistance (e.g., a switched resistor divider array) and the low and high frequency gain adjustment means are provided by continuously variable resistances (e.g., rheostats). In addition, resistances are preferably provided in series with each of the capacitances in the parallel capacitor array (i.e., the array is formed of parallel RC series components), and this array is isolated from the other resistances in the second path by a buffer so that the other resistances do not contribute to the RC filtering characteristics.

The cable compensator is highly advantageous since it allows video signal paths, such as the video imaging chain of an X-ray imaging system, to be readily calibrated for any final cable length to be used at an installation site (this cable length being unknown at the time the system components and compensator are manufactured). Installation and field calibration time is greatly decreased, and image quality for a given X-ray system can be made consistent from one installation site to another. The compensator also avoids the situation where video subsystems are unnecessarily replaced because deficient image quality is seen as arising from a flaw in the video chain, but where it actually arises because the video chain is inappropriately calibrated for the cable length used at the installation site. Further advantages, features, and objects of the invention will be apparent from the following detailed description of the invention in conjunction with the associated drawings.

Brief Description of the Drawings

FIG. 1 is a schematic circuit diagram of an exemplary embodiment of the cable length compensator.

FIG. 2 is a circuit diagram of an exemplary cable length selector suitable for use in the cable length compensator of **FIG. 1**.

FIG. 3 is a plot of gain versus frequency in an exemplary X-ray video subsystem cable, shown for two different cable lengths and both with and without the inclusion of the cable length compensator.

Detailed Description of Preferred Embodiments of the Invention

In the drawings, wherein the same or similar features of the invention are designated in all Figures with the same reference numerals, **FIG. 1** illustrates an exemplary cable length compensator **10** in accordance with the invention. The cable length compensator **10** has two signal paths, a low frequency gain adjustment path ("first path") **16** and a cable length compensation path ("second path") **18**. Each of these paths will now be discussed in turn.

The low frequency gain adjustment path **16** selectively sets the gain (ratio of output signal to input signal) of low frequency input signals as desired, and it includes an input amplifier **12**, a means for adjusting low frequency gain **20**, and an output amplifier **14** (wherein the input and output amplifier **12** and **14** are also shared by the cable length compensation path **18**, i.e., the two paths **16** and **18** share the same input and output). The means for adjusting low frequency gain **20** is preferably a variable resistance which may be set to a desired value, and in the most preferred version of the invention, it takes the form of a rheostat.

The cable length compensation path **18** then includes the aforementioned input and output amplifiers **12** and **14**, with several components interposed therebetween: a means for adjusting high frequency gain **22**, a cable length selector **24**, a buffer **26**, and a compensation network **28**.

The high frequency gain adjustment means **22** is used to set the overall gain of the cable length compensation path **18**, and is preferably provided in the form of a variable resistance such as a rheostat.

The cable length selector **24** is a variable resistance which provides an output which is proportional to the selected cable length (i.e., selection of a longer cable length provides greater output current and voltage). While the cable length selector **24** is illustrated in **FIG. 1** as a simple potentiometer, it is preferably provided in the form of the switched resistor divider array shown in **FIG. 2** (with exemplary resistor values illustrated). In **FIG. 2**, the array **24** includes a double pole five-position cable length switch **100** (i.e., a switch allowing resistor values corresponding to 0 m, 10 m, 20 m, etc.) and a single pole ten-position unit cable length switch **102** (i.e., a switch allowing resistor values corresponding to 0 m, 1 m, 2 m, etc.) so that the voltage across the array **24** may be varied linearly and discretely in proportion to cable lengths varying between 0 - 49 m (with the voltage to ground **104** remaining constant). An RC bridge **106** is preferably provided between the input and ground to serve as a filter for eliminating transient high-frequency switching pulses.

The buffer **26** is provided to isolate the high frequency gain adjustment means **22** and the cable length selector **24** from the compensation network **28**. It is preferably provided by an amplifier (transistor) which provides a fixed amount of high-frequency gain.

The compensation network **28** includes a number of RC (resistor and capacitor) components arrayed in parallel, and having their outputs leading to the summing junction of the output amplifier **14** along with the output from the low frequency gain adjustment means **20** of the low frequency gain adjustment path **16**. Thus, in conjunction with the output amplifier **14**, the compensation network **28** effectively forms an array of high-pass filters, each of which provides frequency-dependent amplification. The quantity of RC components, as well as the "break" (lower cut-off) frequencies they provide, depends on the frequency range over which compensation is required, the degree of fine tuning needed, and the type of cable that will ultimately be used with the compensator **10**. For best performance, the resistance and capacitance values of the compensation network **28** are preferably chosen in accordance with both deterministic principles of circuit analysis and also by empirical testing. An exemplary method of setting RC values during the design of the compensator **10** follows.

First, the low frequency gain adjustment path **16** is calibrated so that it will not interfere with the calibration of the compensation network **28** in the cable length compensation path **18**. A test cable **30** of the same type to be ultimately used with the cable length compensator **10** at the installation site, and having a length corresponding to a medium length setting provided by the cable length selector **24** (e.g., 25 m), is connected to the input end of the input amplifier **12**. The cable length selector **24** is then adjusted to a length setting corresponding to the test cable length. Video signals having varying low frequencies (e.g., 100kHz to 1MHz) and a known signal level are then swept through the test cable **30** and cable length compensator **10**. The low frequency gain adjustment means **20** is then adjusted for unit gain, i.e., so that the output video signal equals the input video signal at low frequencies for the medium-length test cable. (Note that a medium-length test cable **30**, being a good approximation of an "average" cable to be installed in the field, is used to approximate the low frequency voltage drop due to DC cable resistance in both long and short cables having potential use at the installation site.)

The settings for the RC values in the cable length compensation path **18** are then determined. A test cable **30** of the same type to be ultimately used with the cable length compensator **10** at the installation site, and having a length corresponding to the maximum length setting provided by the cable length selector **24**, is connected to the input end of the input amplifier **12**. The cable length selector **24** is then set to the maximum length setting, corresponding to maximum output current/voltage, and the high frequency gain adjustment means **22** is set to its medium setting. Signals having a known level are swept through the test cable **30** at varying high frequencies ranging up to the highest frequency to be accommodated by the video chain (e.g., over a range of 1-20 MHz). The resistor/capacitor values used in each RC path of the compensation network **28**, which determine the breakpoints of these paths, are selected to provide unity gain and a flat response across the range of operating frequencies. Their values may be initially defined by circuit analysis, and can then be confirmed or adjusted by testing.

Once the RC settings have been determined in this manner, the specifications for the compensator **10** have been fully determined for any further compensators **10** to be produced for later use with cables of the same type as the test cable **30**. The RC settings need not be changed unless the cable type to be used with the compensator **10** is changed (or unless the components or circuit/board layout of the compensator **10** is changed, in which case changes in parasitic capacitances may warrant recalculation of RC values). In other words, different compensators **10** with different compensation networks **28** are required for different types of cables, but the same compensator design may be used with different lengths of the cable type for which it was designed.

When further compensators **10** are produced in accordance with the determined specifications, it is desirable to "factory-calibrate" or fine-tune each compensator **10** to account for possible manufacturing and component variations. Fine-tuning of each individual compensator **10** is preferably done in much the same manner as the calibration of the low frequency gain adjustment path **16** and the cable length compensation path **18** during the design phase. A medium-length test cable **30** is provided at the input end of the input amplifier **12**, the cable length selector **24** is adjusted to a corresponding length, and the low frequency gain adjustment means **20** of the low frequency gain adjustment path **16** is adjusted to provide unity gain when the aforementioned low-frequency signal sweep is delivered through the compensator **10**. The medium-length test cable **30** is then removed and replaced with a maximum-length test cable **30**, the cable length selector **24** is adjusted to a corresponding length, and the high frequency gain adjustment means **22** of the cable length compensation path **18** is adjusted so that approximately unit gain is provided across the target frequency range when the aforementioned high-frequency signal sweep is delivered through the compensator **10**.

Once these fine-tuning steps are completed for each individual compensator **10**, they are ready for delivery and use at installation sites. Installation may be visualized with reference to **FIG. 1** by now regarding the cable **30** as being the "site cable" (which is of the same type for which the compensator **10** was designed), and wherein a video imager **32** (e.g., a video camera) provides an input to the compensator **10**. After

installation, so long as the proper type of site cable **30** is provided at the input of the input amplifier **12** and the correct cable length is selected at the cable length selector **24**, the cable length compensator **10** should provide a response (gain vs. frequency profile) which is at least substantially similar to that which would be provided if the cable **30** was not present. Therefore, the frequency profile of the signal coming out of the compensator **10** will be substantially the same as the frequency profile of the signal coming out of the video imager **32**. If the input signal is very low frequency, the cable length compensator **10** acts like an open circuit. The input signal has virtually no cable loss at these frequencies, and the output of the low frequency gain adjustment path **16** is summed with the (negligible) output of the cable length compensation path **18**. The result is a flat response out of the output amplifier **14** across the range of operating frequencies. As the input frequency increases, the capacitive reactance of the lowest frequency breakpoint in the compensation network **28** decreases, thus providing more current to the summing junction of the output amplifier **14**. With proper calibration of the compensation network **28**, the summing current will be exactly proportional to the loss incurring in the cable. As the frequency further increases, the successively higher breakpoints in the compensation network **28** provide current contributions to the summing junction. This compensation continues up to the highest frequency breakpoint. **FIG. 3** provides a plot of frequency versus gain for two cables having lengths of 12 m and 30 m, both with and without the cable compensator **10** installed; it is seen that the cable compensator provides a substantially flat response, that is, it preserves the input signal's frequency profile and will thereby prevent the cables from having a significant effect on the transfer functions of the other components in the signal chain. In contrast, when the cable compensator **10** is not used, signal level dropoff is significantly greater at higher frequencies (particularly with longer cables).

Variations on the selection and arrangement of the aforementioned components are considered to be within the scope of the invention. Initially, while it was previously noted that the preferred low frequency gain adjustment means **20** is a rheostat, it should be understood that any other form of continuously-variable resistance could be used, as well as a discretely variable resistance (e.g., a switched array of resistors allowing

selection of discrete resistance values). However, a continuously variable resistance is preferred. The low frequency gain adjustment means **20** preferably uses simple variable resistors such as rheostats, potentiometers, or resistor arrays for cost reasons, though more complex and expensive components (e.g., programmable gain stages) could also be used. Similarly, it is noted that the variable resistance of the high frequency gain adjustment means **22** may be provided in a wide variety of forms apart from a rheostat, e.g., those noted for the low frequency gain adjustment means **20** described above.

Likewise, apart from the potentiometer/resistor array previously described as being suitable for use as the cable length selector **24**, the variable resistance of the cable length selector **24** could instead be provided in any of the forms that can be used for the low frequency gain adjustment means **20** and the high frequency gain adjustment means **22**. However, it is emphasized that a variable resistance which allows a discrete and linear variation of potential in proportion to cable length is particularly preferred.

As another example of an alternative embodiment of the invention, it would be possible to replace the variable resistances of the high frequency gain adjustment means **22** and the cable length selector **24** with a single variable resistance, though this would make calibration and later cable changes significantly more difficult. It would also be possible to remove the buffer **26**, in which case the resistance(s) interposed between the compensation network **28** and the output of the input amplifier **12** would contribute to the reactions of each path in the compensation network. Again, in this case calibration and subsequent cable selection is also made considerably more difficult.

Additionally, it is noted that the input amplifier **12**, output amplifier **14**, and buffer **26** may be provided by various forms of amplifiers, e.g., operational amplifiers or transistor-based amplifiers. Most preferably, they are provided in the forms noted above, i.e., operational amplifiers for the input amplifier **12** and output amplifier **14**, and a transistor amplifier for the buffer **26**.

Regarding the aforementioned factory calibration steps, it is noted that other methods of fine-tuning compensators **10** may be used. As an example, fine-tuning could instead occur at the installation site after the site cable **30** has been installed and the cable length selector **24** has been set to a corresponding length (i.e., the site cable **30**

may be used to fine-tune both the low frequency gain adjustment path **16** and the cable length compensation path **18**). In this case, the compensator **10** will still be adequately tuned to accommodate other site cables **30** of the same type by merely selecting the appropriate settings on the cable length selector **24**. However, for the sake of efficiency, factory fine-tuning is preferred over fine-tuning at the site.

It is also noted that while the foregoing description discusses tuning of the low frequency gain adjustment path **16** and cable length compensation path **18** so that unit gain is provided across the range of target frequencies, they may instead be designed and tuned to provide a different level of amplification or attenuation.

The invention is not intended to be limited to the preferred embodiments described above, but rather is intended to be limited only by the claims set out below. Thus, the invention encompasses all alternate embodiments that fall literally or equivalently within the scope of these claims. It is understood that in the claims, means plus function clauses are intended to encompass the structures described above as performing their recited function, and also both structural equivalents and equivalent structures. As an example, though a nail and a screw may not be structural equivalents insofar as a nail employs a cylindrical surface to secure parts together whereas a screw employs a helical surface, in the context of fastening parts, a nail and a screw are equivalent structures.